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EXTINGUISHING AMMUNITION FIRES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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It is generally conceded that ammunition fires are the main reason for the total loss of armored vehicles in combat. We are investigating methods of extinguishing these fires. We have thus far demonstrated that it is possible to extinguish propellant fires by the use of conventional extinguishing agents. Since propellant is the principal combustible in ammunition compartments and other storage places, this opens up the possibility of controlling ammunition fires.

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20. Abstract (con't)

We have achieved the following results:

1. In the event of an ignition of a propellant bed, we can detect the fire and activate extinguishers in about 30 milliseconds. It is necessary to cool the burning solid in order to fully quench the fire. Water based foams have been successfully used for this purpose. The water cools the burning material while the expansion of volume due to the foaming additive allows greater coverage from a given amount of extinguishant. Use of an additional extinguisher containing Halon 1301 allows even quicker extinguishment of the fire.

2. In the event of a shaped charge jet attack on a cartridge case containing M30 propellant, we can save 2 of the original 4 kg of M30, using both water based foam and Halon 1301. In addition, the propellant that burns does so inefficiently with greatly reduced intensity. A lot of the heat liberated is absorbed by the water. The propellant burn would probably not be catastrophic to either vehicle or crew members.

3. Shaped charge jets have been used to attack fully loaded 105 mm kinetic energy rounds. Most of the M30 propellant burned, but with poor efficiency. The flames associated with the burning process were significantly reduced. It is quite possible that crew members could have survived the burning of the propellant in the presence of the extinguishing agents.

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I. INTRODUCTION

The total loss of an armored vehicle in combat is generally caused by an ammunition and/or fuel fire. In an effort to reduce such losses, the U.S. Army is equipping its latest tank, the M1, with a system to automatically detect and extinguish fuel fires. This system incorporates the latest state of the art electronic and mechanical components to achieve the millisecond range response time needed to protect both the crew and the vehicle. Tests have demonstrated that it is possible to detect a diesel fuel fire and extinguish it in 100 milliseconds.[1]

In the M1 tank, ammunition is stored in a vented compartment at the rear of the turret. This compartment is normally sealed off from the crew volume, so that the crew and vehicle may survive a direct hit on the main ammunition supply. However, no technology has been developed to extinguish ammunition fires. Even in an arrangement such as the M1's ammunition compartment, a large portion of the ammunition may be destroyed even if only one round is struck initially.

In all other US armored vehicles, including the M60 tank, ammunition is stored in the crew volume using the vehicle's armor as protection. A hit which perforates the armor and strikes the ammunition will probably cause complete destruction of the vehicle and its crew. There is an obvious need for an extinguishing system which is capable of quenching an ammunition fire, thus limiting the destructive effects to only the round initially struck. Therefore, a decision was made to determine if it would be possible, using technology similar to that developed for the M1 tank, to detect and extinguish an ammunition fire in an armored vehicle in the short period of time between a hit and a catastrophic event.

Previous tests conducted at the Ballistic Research Laboratory have demonstrated convincingly that a direct hit by a shaped charge jet on the explosive contained in a 105 mm HEAT warhead causes immediate detonation of the explosive.[2] However, other rounds positioned alongside the warhead take from many milliseconds to several seconds before ignition or cook off occurs. This is long enough for a rapid system to extinguish the fire. Therefore, in this case of a shaped charge jet striking a high explosive warhead, there may be sufficient time to act and prevent additional rounds from exploding.

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1. Dicker, R.J.L., *"Countering the Crew Compartment Explosion," International Defense Review 5, pp 120-122, 1979.*
2. Melani, G., Frey, R.B., and Carter, S.M., *"Determination of the Residual Jet Parameters Required to Initiate Cased Explosive Charges," BRL Memo Report No. 2753, May 1977.* (AD B019791L)

Looking at a different situation, in which attack by a conditioned shaped charge jet occurs on the propellant section of the round, normally only a small portion of the propellant reacts immediately.[3] Most of the propellant grains are scattered about to ignite and burn a short time later. A fast response extinguisher may prevent the burning of most of this propellant from the round initially struck. This should prevent ignition of adjacent rounds which have been cracked open by fragments from the first round.

II. EXPERIMENTAL

A. Materials

Three brands of fire extinguishers were employed. Two of these are currently in use in the M1 tank. These use extremely fast discharge rate valves. They were manufactured by Crown Systems and Marotta Scientific Controls, Inc. These extinguishers are solenoid valve types requiring a 24 volt DC (10 amp) source for actuation. The third system, "Pre-Calc" manufactured by Chemetron Fire Systems, is slower in initial response and discharge time. However, it utilized a 110 volt AC solenoid operated pilot valve. Since this was more convenient to use and the extinguisher flow was adequate for our needs, the "Pre-Calc" extinguisher was used for most of this work.

The M30 propellant and the empty 105 mm cartridge cases were standard types. They and the M392A2 rounds were obtained from the APG Ammunition Supply. These rounds are 105 mm discarding sabot kinetic energy type. They are one of the rounds used in the M68 gun, standard on the M1 and M60 tanks. These rounds were chosen because they are directly applicable to the problem we are attacking and they do not present the problem in handling that shaped charge rounds cause after they have been exposed to a fire.

The 81 mm diameter precision shaped charges were obtained from the Warhead Mechanics Branch of the Terminal Ballistics Division of the BRL.

The ethylene glycol used was standard automotive type inhibited permanent antifreeze.

Foam concentrate was purchased from National Foam Inc. Two types of foams were used, a standard one known as AOW+3 and a low temperature type called AOW3 + Cold Foam. Since ethylene glycol was used in formulating the foam solutions, concentrations up to 20% foam agent were used, instead of the normally recommended 3%. The high concentration was needed to obtain

[3] *Majerus, J.N., Merendino, A.B., "Observations of Shaped-Charge Jet/M30 Propellant Reactions," BRL Technical Report No.02108, Sept. 1978. (AD A062299)*

good foam expansion at -14^{o}C. At 0^{o}C, 6% AOW3 + Cold Foam gave good results even with one-third antifreeze present in the formulation.

Photographic coverage was obtained by using two Teledyne Milliken 16 mm cameras. Normally one was operated at 100 fps, the other at either 500 or 300 fps.

B. Procedures

1. An experiment was conducted to determine if it were possible to extinguish propellant fires using conventional extinguishing agents. A train of overlapping M30 propellant grains (the propellant used in the U.S. Army's 105 mm tank gun round) was constructed on a section of angle iron and placed into a gas chamber. The train extended out of the chamber so that the propellant could be easily ignited using a propane torch. The chamber was approximately 75 cm long by 35 cm diameter. A 12 mm diameter pipe was attached to one end of the chamber and a 60 mm hole cut into the other end. The angle iron with two overlapping rows each containing 25 grains of M30, could be easily slid into or out of the chamber. A schematic of the test setup is given in Figure 1.

In use the chamber was flushed for 10 minutes with a test gas. The propellant was placed onto the angle iron with some grains extending out of the chamber. The propellant was ignited and observations on the combustion behavior were made as the burning progressed into the chamber. Depending on the gas inside the box, combustion either continued with visible flame or the flame was extinguished and only fizz burning occurred inside the box.

2. In other tests, the angle iron, with M30, was placed on the ground and ignited. A stream of liquid extinguisher was directed at the burning propellant. Observations were made as to how easily combustion was stopped.

3. The combustion of single grains of M30 was studied using a modified Oxygen Index Flammability Tester. A grain of M30, wrapped in a nichrome wire, was suspended in a glass chimney. Mixtures of two gases, in this case extinguishant plus air, could be passed through the apparatus. The single grain could be ignited electrically in the controlled atmosphere. The most efficient extinguishing agent would be the one which prevented flame with the highest percent of air in the mixture (lowest percent of extinguishant). A schematic of this apparatus is presented in Figure 2. The grain of M30 was suspended in the glass chimney and the system flushed with test gas for 10 minutes. The nichrome wire was then heated and observations were made on the combustion of the M30.

4. For field testing, a box was constructed from 25 mm thick steel. The interior dimensions were 41 cm wide, 74 cm high and 104 cm deep. The front of the box was left open. This permitted high speed (500 fps) camera coverage even when the front was sealed with a plexiglas sheet. A vent 30 cm by 41 cm was cut into the top of the box. A pile of 4 kg of loose M30 was placed on the bottom of the box to simulate a burning 105 mm round. An acceptor round containing 4 kg of M30 was exposed to the flames from the burning material. The acceptor round consisted of a slotted sleeve and a slotted 105 mm cartridge case. The slots were aligned to allow the propellant in the case to be exposed to the environment. Figure 3 shows the slots in the sleeve and case.

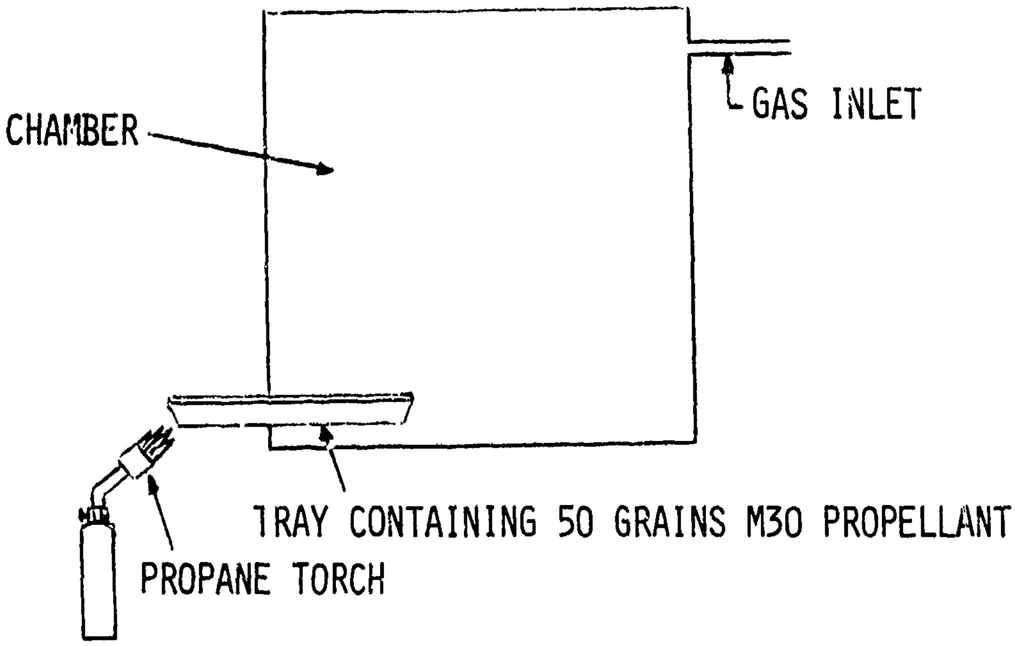

FIGURE 1. GAS CHAMBER

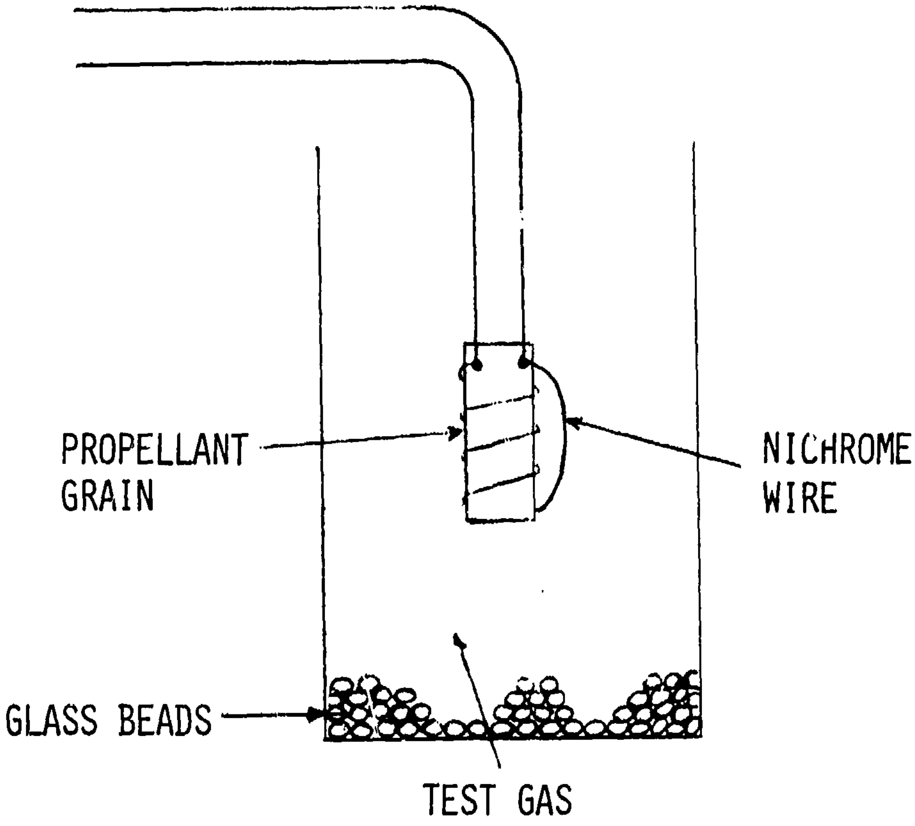

FIGURE 2. MODIFIED OXYGEN INDEX FLAMMABILITY TESTER

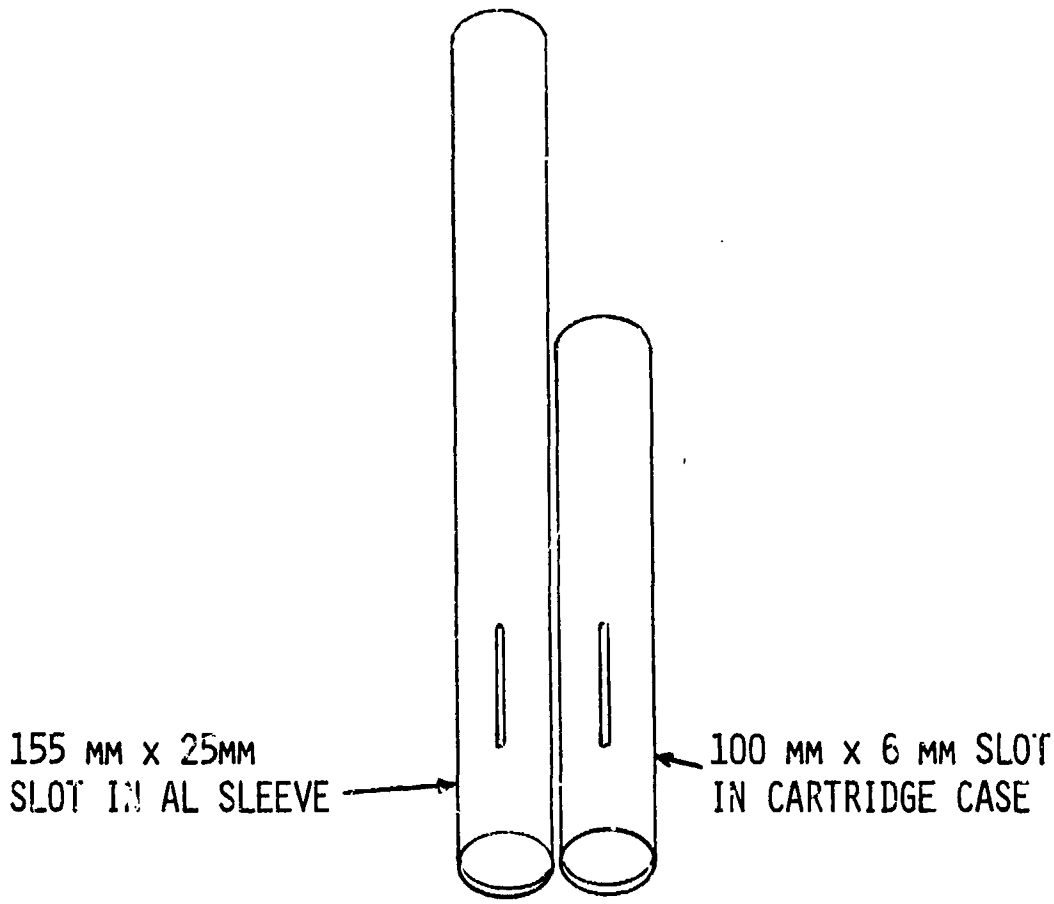

FIGURE 3. 105 MM CARTRIDGE CASE AND ALUMINUM SLEEVE

An electric match and black powder were used to ignite the 4 kg of loose M30. A solar cell detector signaled a sequential timer when the fire started. An extinguisher was activated electrically and Halon 1301 or other extinguishants piped into the test box. A plexiglas front cover was used in an attempt to keep the halon inside the test box. A representation of the test setup is given in Figure 4.

5. Subsequent experiments were performed using water based foaming agents as fire extinguishants. For this work, the plexiglas shield was removed and the extinguisher situated 3 meters from the front of the box. A foam generating nozzle was fabricated and screwed into the discharge port of the extinguisher. Upon detection of a fire, the foam was sprayed in the general direction of the box. Foam was used to increase coverage of the spray. Only materials generally considered non-toxic were considered for the formulations. Therefore the materials in the formulation have been limited to water, calcium chloride, ethylene glycol and conventional fire fighting foaming agents. A schematic of the setup is given in Figure 5.

6. In an attempt to model the real combat situation more closely, tests were conducted in which a cartridge case containing 4 kg of M30 propellant was placed on the bottom of the test box. One hundred seventy-eight mm of armor were placed over the hole in the top of the box. An 81 mm shaped charge was set up to fire its jet through the armor and into the box. The cartridge case was positioned in such a way that the jet passed through the case and propellant or the case was placed out of the path of the jet. In the latter situation the case was hit only by spall from the armor plate. Initially the extinguishers were set up the same way as in procedure 5. However, the blast from the explosive in the shaped charge was sufficient to knock over the extinguishers. Therefore, holes were cut into the sides and back of the box. The extinguishers were secured at the box so that the extinguishant would flow right into the test setup. A schematic of the setup is given in Figure 6.

7. In this procedure, M392A2 rounds (105 mm kinetic energy type) were set in the bottom of the box. Armor was placed over the opening in the top of the box and an 81 mm shaped charge fired through the armor into the box. Conditions could be arranged so that the round would be hit by the jet or just by spall. The extinguishers were secured at the test box.

III. RESULTS AND DISCUSSION

The chamber experiments (procedure 1) showed that it is indeed possible to prevent gas phase burning of M30 propellant if it is subjected to the proper atmosphere. The results of these tests are given in Table 1.

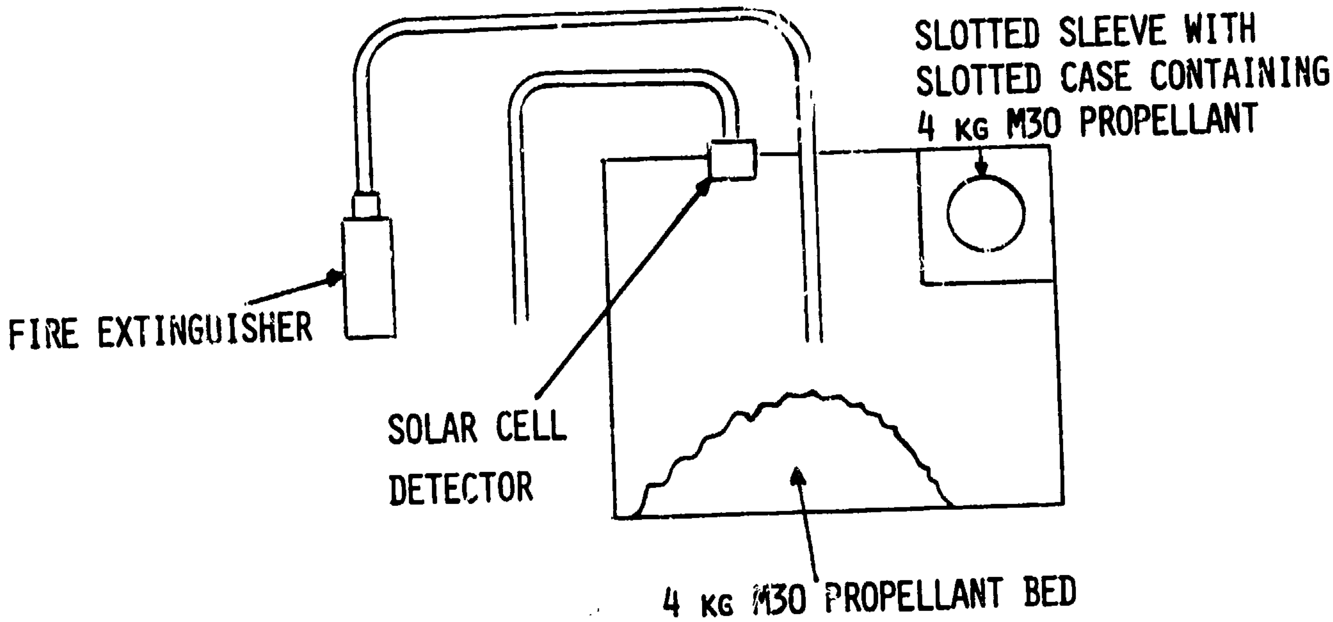

FIGURE 4. FIELD TEST SETUP

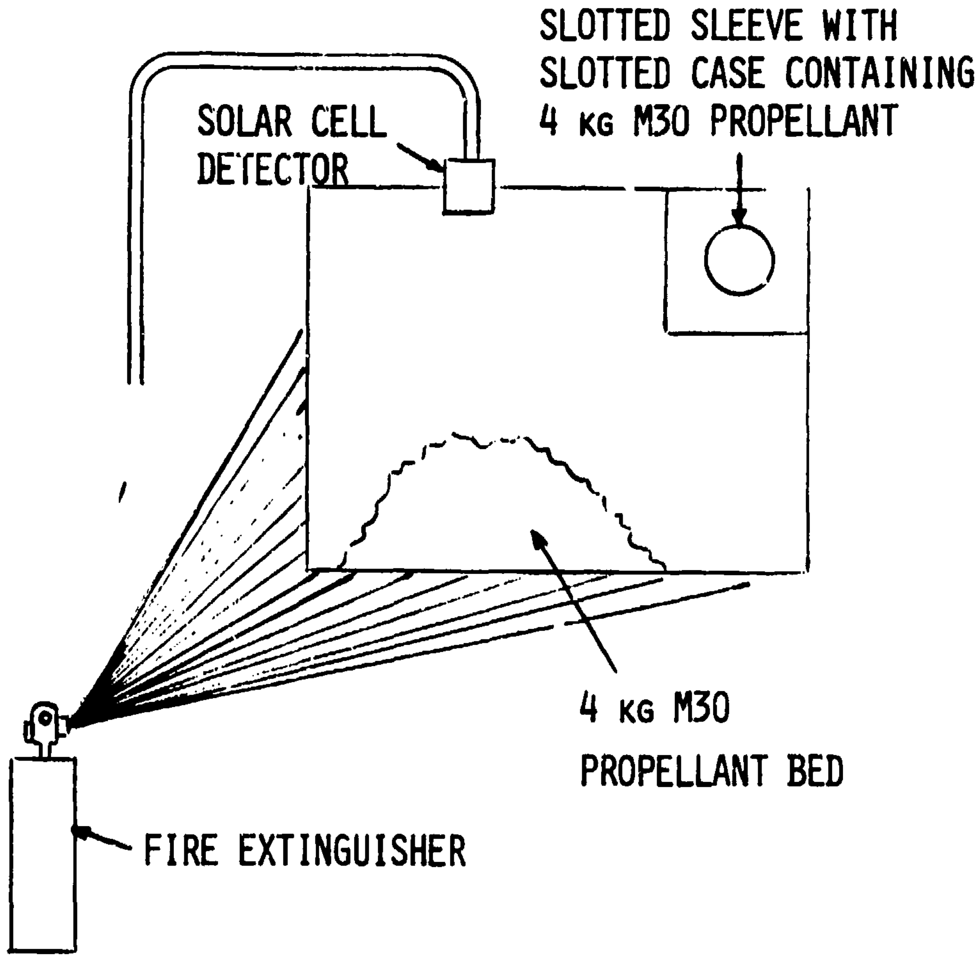

FIGURE 5. FIELD TEST SETUP FOR FOAM SPRAY

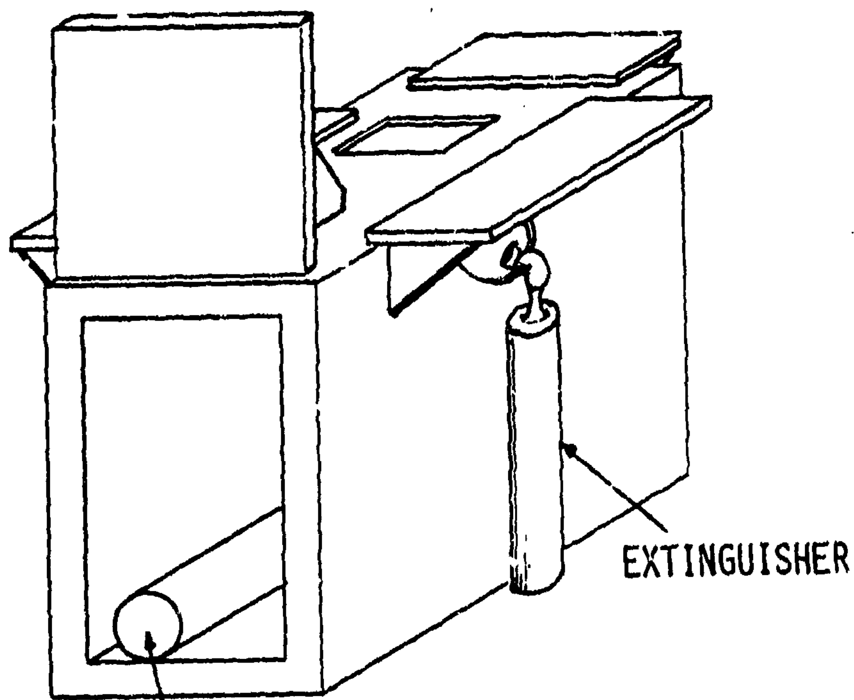

FIGURE 6. FIELD TEST SETUP WITH EXTINGUISHER SECURED AT BOX

Table 1. Chamber Tests Results as Flame Entered Chamber

Gas	
Halon 1301	Flame extinguished solid continued to fizz burn
Nitrogen	Flame extinguished solid continued to fizz burn
Carbon Dioxide	Flame extinguished solid continued to fizz burn
Argon	Flame extinguished solid continued to fizz burn
Halon 1211	Intense fire inside chamber

In no case was it possible to stop fizz burning. However, it was felt that fizz burning could be accepted as long as there was no flame to transfer burning to nearby exposed propellant. The surprise was that the M30 burned very strongly in a Halon 1211 atmosphere. The Halon 1211 is considered an excellent extinguishing agent for hydrocarbon fires.

In procedure 2, using liquid and solid agents directed at burning grains of M30, it was found that flame could be extinguished if a high vapor pressure extinguishant was used to displace the air in the vicinity of the burning grains. Fizz burning continued. The evaporating agents were able to quench the gas phase burning but not the solid fizz burn of grains untouched by liquid. When all of the burning grains were covered with liquid or solid agent all combustion ceased. Here a cooling mechanism was sufficient to completely quench the M30. Results of these tests, using several condensed extinguishants, are given in Table 2.

Table 2. Results Using Condensed Phase Extinguishants

Agent	Results
Water	M30 grains continued to burn with flame even when lower sections of grains were immersed in liquid. Only when liquid was directed at burning grain was flame extinguished.
Liquid Nitrogen	Evaporating gas extinguished flame. Solid continued to fizz burn. All burning ceased when grains were covered with liquid agent.
Carbon Dioxide	Solid carbon dioxide formed on M30. Flame was extinguished. Solid M30 continued to fizz burn until a large quantity of agent was directed at the burning grains.

These experiments demonstrated that it is possible to completely quench the burning propellant if cooling material is directed onto the grains.

Even though none of the gaseous extinguishants used in the chamber tests stopped fizz burning, four of the agents immediately quenched flames inside the

chamber. There was no way to distinguish among these four as to efficiency. This situation would probably be true in respect to any future agents to be tested. Therefore, the single grain extinguishing experiment was tried. In this setup of procedure 3, the atmosphere surrounding the propellant grain can be varied. Initially neat gaseous agent was used. In subsequent experiments controlled ratios of agent to air were to be tested. Unexpectedly, the single grain heated electrically in neat Halon 1301 burst into flame. The evolved gases simply pushed the Halon 1301 gas away from the M30. Dilution of the evolved gases did not occur since the flow of the halon was very slow and the volume of the system was small. While air may aid in flame formation, flame can be established if the evolved gases are in a high enough concentration. In the chamber experiments of procedure 1 the gas flow was faster and the volume of the chamber larger. The test gases were able to dilute the evolved gases so flames were extinguished. These two experiments showed that a dilution mechanism is important in preventing flames. If the gases coming off a fizzing grain can be diluted with an inert gas, flames will not be established. A representation of the possible behavior of a grain of M30 under different conditions at atmospheric pressure is given in Figure 7.

In procedure 4, experiments using the steel box and Halon 1301 showed that if the halon was piped into the box within several hundred milliseconds after the solar cell detected the ignition of the black powder and M30, it was possible to extinguish flames. The M30 continued to fizz burn. In a second or two after the end of the halon flow, sufficient gases were evolved to surround the burning solid with combustible vapors. Flame reappeared and full scale burning occurred. The acceptor shell was ignited in about four seconds. This behavior, extinguishment of flame, followed by its reappearance, was the best experimental result obtained with Halon 1301. It became obvious that it would be necessary to quench all burning of the M30 to prevent ignition of the acceptor round. Liquids, with their inherently greater cooling effect, would be needed.

Tests were then conducted using water - ethylene glycol mixtures. After detection of fire by the solar cell, the liquid extinguishant was piped into the steel box through 3 meters of tubing as in Figure 4. Several hundred milliseconds elapsed between ignition of the black powder and delivery of the liquid extinguishant to the burning propellant. It was found that a minimum of seven liters of extinguishant was required to quench the pile of 4 kg of burning M30. This large amount of extinguishant was required because the fire had become well established in the time span between ignition and when the liquid actually got to the fire. However, the acceptor round did not ignite even though it was exposed to flame during this time.

In procedure 5, foaming agents were added to a water - ethylene glycol mixture to obtain a large volume of coverage. This means that the extinguishant does not have to be aimed directly at the fire site. As long as the material flows in the correct general direction, extinguishant will get to the fire. The premixed solutions were put into conventional "Pre-Calc" fire extinguishers. The extinguishers were merely aimed at the front opening of the steel box (no plexiglas covering the front). Using this method of getting material to

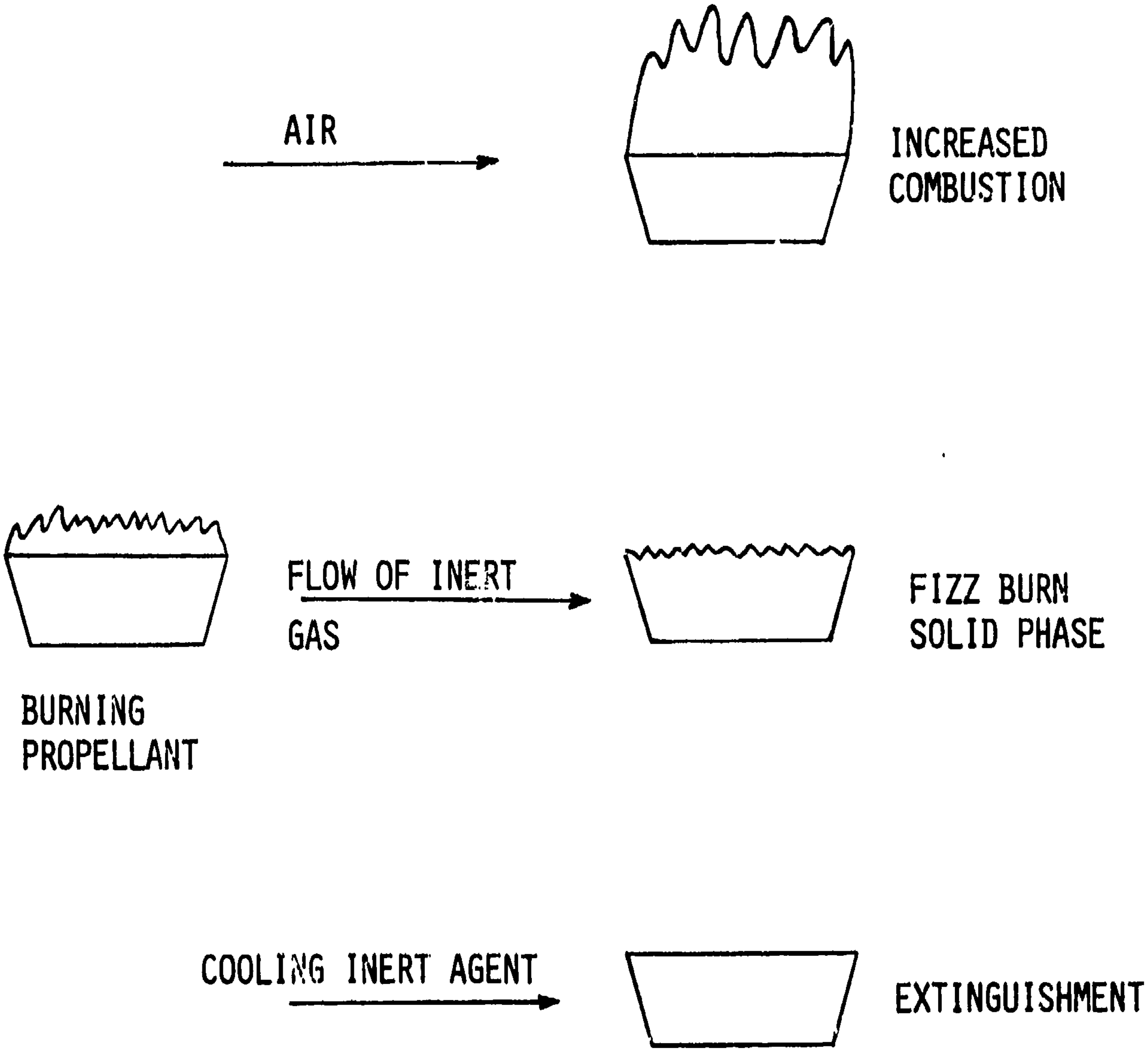

FIGURE 7. FATES OF A GRAIN OF PROPELLANT UNDER 3 DIFFERENT CONDITIONS

the fire, flow of liquid extinguishant could be detected on the films several milliseconds after ignition. It was possible to extinguish the M30 fire using only four liters of foam extinguishant. This is rationalized on the basis that the quicker the extinguishant is delivered to the fire site, the less intense the fire and the easier it is to extinguish. Therefore less liquid is required to quench the fire and save the acceptor cartridge case.

Experiments were then done using two extinguishers, one containing 7 kg of Halon 1301 and the other four liters of foam solution. Since vehicles are already being equipped with halon to suppress hydrocarbon fires, it was reasoned that halon extinguishers would probably be activated by propellant fires as well as by hydrocarbon fires. It was found that the flames were extinguished more quickly when the two extinguishers were used. The Halon 1301, possibly due to lower viscosity, begins discharge about ten milliseconds before flow of the water based foam begins. The halon is capable of stopping gas phase burning, as we had already discovered. The foam which followed easily quenched the fizz burning propellant. Therefore, the two extinguishants together performed better than would be expected on a simple additive basis, since the halon cannot control the M30 fire by itself. Results of tests using electric match igniters are given in Table 3.

The thought of combining Halon 1301 and foaming extinguishant in one container is very attractive. However, it is well known that Halon 1301 and similar materials must be kept completely free of water since hydrolysis occurs giving acid products. This is unacceptable in normal extinguishers. There is also the problem of expelling the halon before the foaming agent. The beneficial interaction of the two extinguishants depends on getting the halon to the fire with the foam following closely behind. If a single extinguisher were engineered to expell the halon first, there might be insufficient pressure remaining to discharge the foam efficiently.

In procedure 6 a shaped charge jet was conditioned by passing through 178 mm of armor and directed into the experimental box. For the first shaped charge shots, the device was aimed so that the jet would miss the cartridge case of M30. Spall from the armor plate hit the case. Often the spall merely peppered the case with no punctures or made only a few small holes in the case with no fire. The fine spall particles apparently lost the ability to penetrate the steel cartridge case after passing through 56 cm of air. In one instance the case was struck by a large spall particle (spall ring) and fire was observed. There were also cases in which the small spall particles did indeed cause ignition. Spall initiated fire is particularly difficult to extinguish since the fire is inside the cartridge case. There is no efficient method of getting the extinguishant to the site of the fire. In most cases, the shaped charge was aimed so that the conditioned jet went through the cartridge case and propellant. It was found that only about 50% of the M30 in the case could be saved. However, the presence of the extinguishant greatly reduced the intensity of the fire.

Table 3. Summary of Results Using Electric Match Igniter

Propellant	Extinguishing Agent	Extinguisher Position	Delay Between Ignition and Extinguishant Flow	Results
4 kg loose M30, 4 kg M30 in slotted case.	4 liters 10% AOW + 3 in water - antifreeze mixture at 4 MPa.	2 meters from front of box.	1.1 seconds	Fire almost out, came back strong, all M30 burned.
4 kg loose M30, 4 kg M30 in slotted case.	4 liters 6% AOW + 3 in water - antifreeze mixture at 4 MPA + 7 kg Halon 1301 at 3 MPa in second ext.	2 meters in front of box	1 second	Fire out almost immediately when extinguishants started to flow. Halon 1301 flowed faster and removed flame faster than foam.
4 kg loose M30, 4 kg M30 in slotted case.	4 liters 6% AOW + 3 in water at 5 MPa	2 meters in front of box.	120 milliseconds	Only about 10% loose M30 burned. No M30 in shell burned.

The M30 that burned did so at reduced efficiency as evidenced by greatly diminished visible flame. Much of the heat that was generated was absorbed by the extinguishant. A large amount of the water was vaporized. This action limited the temperature rise. Therefore, it may well be possible that even though 2 or 3 kg of M30 were consumed, the temperature increase in the vicinity may not have been too great. Crewmen inside a vehicle might have been able to survive such an event. Typical results are given in Table 4.

As described in procedure 7, conditioned jets were shot into the propellant section of M392A2 rounds. When only one round was used, about 20% of its propellant could be saved using one foam plus one halon extinguisher. However, the intensity of the fire was greatly diminished due to the cooling effect of the water-based extinguishant. Tests were done using two M392A2 rounds in the box. These rounds were placed side by side. The jet hit one round. Here also, about 20% of the propellant from the struck round was saved. The second round was only dented. It neither burned nor broke open. The intensity of the fire was low, just as in the case of a single round. Results are given in Table 5.

IV. CONCLUSIONS

The following conclusions may be drawn from this work:

1. Using readily available components, it is possible to detect and quench a fire initiated by an electric match buried in a bed of propellant fast enough so that it should not become a catastrophic event.

2. Halon 1301, commonly used as an extinguishant for hydrocarbon fires, is not sufficient to extinguish a fire in a bed of M30 propellant.

3. Water based foams are sufficient to extinguish fires in propellant beds.

4. A combination of Halon 1301 and water based foam, in separate pressurized containers, extinguishes a propellant bed fire even more quickly than foam alone.

5. When the propellant in a M392A2 round is initiated by an extremely energetic source, such as a shaped charge jet, rapid application of both Halon 1301 and water based foam saves at least 20% of the propellant and reduces the intensity of the fire associated with the propellant that does burn.

6. Use of appropriate extinguishing agents can reduce the destructive effects of propellant fires. This should lead to an increase in the survivability of armored vehicles and lessen the danger to crewmembers.

Table 4. Summary of Results Using 81 mm Shaped Charges and Cartridge Cases

Target	Path of Jet	Extinguishant	Extinguisher Position	Results
4 kg M30 in cartridge case.	Jet aimed off to side. Spall from armor plate hit case.	4 liters 20% AOW + 3 CF* in water at 4 MPa + 3 kg Halon 1301 at 4 MPa in second ext.	2 meters in front of box.	5 small holes in case. Largest 6 mm x 3 mm. No fire.
4 kg M30 in cartridge case.	Jet aimed off to side. A large spall particle hit case and broke case open.	4 liters 20% AOW + 3 in water at 4 MPa + 2 kg Halon 1301 at 4 MPa in second ext.	2 meters in front of box.	Fire appeared out. Reignition occurred. All M30 burned.
4 kg M30 in cartridge case.	Jet aimed off to side. Spall from armor plate hit case.	6 liters 20% AOW + 3 CF in water at 4 MPa + 3 kg Halon 1301 at 4 MPa in second ext.	1 meter in front of box.	Blast knocked over Halon 1301 extinguisher. Cartridge case peppered by spall. No holes. No fire.
4 kg M30 in cartridge case.	Jet aimed off to side. Spall from armor plate hit case.	6 liters 20% AOW + 3 CF in water at 4 MPa + 3 kg Halon 1301 at 4 MPa in second ext.	1 meter in front of box.	Blast knocked both extinguisher off target. Case had many small holes. All M30 burned.
4 kg M30 in cartridge case.	Jet into center of case.	2 extinguishers each 6 liters 6% AOW + 3 in water at 4 MPa	Next to box.	Big fire ball. All fire out in 3.2 seconds. 50% of M30 saved.

*CF refers to Cold Foam

Table 4. (Continued)

Target	Path of Jet	Extinguishant	Extinguisher Position	Results
2 cartridge cases, side by side each 4 kg M30	Jet into center of 1 case.	2 extinguishers each 6 liters 6% AOW + 3 in water at 4 MPa + 3 kg Halon 1301 at 4 MPa in third ext.	Next to box.	Saved 50% of M30 in case that was hit by jet. Saved all M30 in second case, which was dented.
2 cartridge cases, one on top of other. Each had 4 kg M30	Jet through both cases.	2 extinguishers each had 6 liters 6% AOW + 3 in water at 4 MPa + 3 Kg Halon 1301 at 4 MPa in third ext.	Next to box.	Most of M30 burned, but without large flames. Slow burn due to presence of extinguishers.

Table 5. Summary of Results Using 81 mm Shaped Charges and M392A2 (105 mm) Rounds

Target	Path of Jet	Extinguishant	Extinguisher Position	Results
One M392A2 round	Jet into center of propellant section.	2 extinguishers each 6 liters 6% AOW + 3 in water at 4 MPa + 5 kg Halon 1301 at 4 MPa in third ext.	Next to box.	About 20% of propellant saved. Intensity of fire greatly diminished due to presence of extinguishant.
Two M392A2 rounds, side by side.	Jet into 1 round.	2 extinguishers each 6 liters 6% AOW + 3 in water at 4 MPa + 7 kg Halon 1301 at 4 Mpa in third ext.	Next to box.	Saved 20% of propellant in case hit by jet. Second round was dented but it did not break up and it did not burn. Intensity of fire low.
One M392A2 round	Jet into center of propellant section.	2 extinguishers each 6 liters 6% AOW + 3 in water at 4 MPa + 7 kg Halon 1301 at 4 MPa in third ext.	Next to box.	Saved 20% of propellant. Lots of foam in box at end. Low intensity fire out in 300 milliseconds.

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